# THE EARTH

## ITS NATURE AND HISTORY

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*The Forum Series*

# THE EARTH

## ITS NATURE AND HISTORY

BY

EDWARD GREENLY

D.Sc., F.G.S., &c.

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TO THE MEMORY OF

MY WIFE ANNIE

THE LAST ACT OF WHOSE LIFE WAS TO
RE-READ CRITICALLY THE MANUSCRIPT
OF THIS BOOK

# PREFATORY NOTE

THIS little book is intended for the general reader who desires to know something of what has been ascertained by Geology concerning the nature and history of the Earth, and of the methods by which that knowledge has been acquired. It is also intended for the reader who desires, as he traverses the country, to be able to interpret for himself, in some measure, the leading phenomena which come before him.

It must, however, be clearly realised that the book is excessively condensed. Consequently, it is not always possible to give the evidence on which important statements are founded. Moreover, geologists into whose hands the book may fall are requested to bear in mind that the same limitation of space compels me to make certain statements in a highly generalised manner, without the due qualifications which would, of course, be found in larger works.

E. G.

*February*, 1927.

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## CHAPTER I

# Introductory

THIS is a very small book on a very great subject: it is an attempt to condense into a few pages the nature and the history of the Earth on which we live.

But that very phrase "on which we live" is grossly inadequate: inadequate to the degree of serious illusion, for it blinds us to our true relations to the Earth, which are far more intimate. This book, for example, may seem to be something independent of the Planet. But the metal of the printing-press, the ink, the paper, are derived from, are essentially portions of, that planet. For everything we need and use, we are dependent on it. More still. We read the book with eyes; we apprehend its ideas with a brain, and these are organs of a body. Now animal bodies, our own included, are composed of matter assimilated, mediately or immediately, from the bodies of plants, and the bodies of plants are derived from the body of the Earth. So also are water and air. Take away food, water, and air; and the book, with its ideas, would soon be non-existent for us.

Unsophisticated Early Man, wiser in his simplicity than some of his posterity, spoke of the Earth as the Great Mother. In the light of the Science of our time, his primitive metaphor takes on a deeper meaning. No longer are we placed, by an arbitrary fiat, as aliens and pilgrims on this world; the sophistries of ages melt away. We are children once again, with kinship to all other things.

Yet, Early Man's glimpse of the motherhood of Earth was after all inadequate. We depend upon the existence of our parents for a moderate period only. But from the Great Mother we are never weaned. Our bodies, with whose functions those of our mind are inextricably bound-up, are actually portions of the body of the Earth, passing through certain special phases of change. We are far more than children of the Earth. From birth to death we are of the Earth's own body. In our most exalted moments, we are of the Earth's own life.

## CHAPTER II

# The Earth as a Whole

EVEN of the Solar System, the Earth is but a minor member. Compared with the Stellar Universe, it is an ultra-microscopic speck. Astronomy has taught us this lesson so thoroughly that most of us have come to regard the Planet as quite a small body. If, however, we institute a different kind of comparison, the ratio becomes hardly less surprising in another way. Looking at some small object, such as a chair, we can picture the whole of it, in all its parts, without difficulty. Walking round and ascending to the top of some large building, such as York Minster, we find that a perceptible mental effort is required to form a mental picture of it as a whole. But if, even after many journeys, we try to form an idea of Great Britain as it really is, on its natural scale, we find that we can do no such thing; that we are unable to call up to mind all at once, unable mentally to see an object 600 miles in length. We may perhaps bring all the parts of the building into consciousness together; but to do likewise with all parts of Britain is beyond our power. What we really do is to call up the figure shewn upon a map, then memories of hills, rivers, plains, or sea-coasts which we have actually seen; and combine the two as best we can. We do not *see Britain*: we form a sort of substitutionary picture of it, and that substitutionary picture is our idea of Britain. What then of the whole Planet! We know it to be spherical. We see the horizon to be circular. But if we attempt to continue the curve on its true scale, we are utterly baffled. All we can do is to look at artificial globes, then at some visible tract of land or sea, and, making a combination, think of as large a globe as we can. The substitutionary picture thus obtained is our idea of the Earth. But the Earth as it really exists, with all its continents and oceans, a slowly curving form whose antipodes are 7,900 miles beneath our feet, we never picture. It is gigantic past our utmost faculties of imagination.

Bearing this well in mind, let us proceed to one or two salient facts concerning its constitution. The Planet, being slightly flattened at the poles, is not properly a sphere, but a spheroid. Its exterior is composed of three spheroidal shells—the Atmosphere, Hydrosphere, and Lithosphere; while the enormous internal core which they enclose may be termed the Endosphere. The thickness of the Atmosphere, or shell of gas, is not precisely known, but probably exceeds 150 miles. The Hydrosphere, or shell of water, which we call the Ocean, covers about three-fourths of the surface. Were it spread over the whole globe on an even floor, its thickness would probably be about 8,000 feet. The ocean-floors, as a whole, are gently undulating plains at depths of about 12,000 feet. But in certain relatively narrow troughs which, unexpectedly, are all near mountainous land, depths exceeding 27,000 and in one case attaining 30,930 feet have been found. In fact, these profound hollows are the oceanic counterparts to mountain-chains. The Lithosphere, or sphere of rock, is the shell whose surface is our own habitat. The mean height of its continents above sea-level is about 2,400 feet, but its extreme height is 29,000 feet; so that its extreme relief from highest mountain peak to lowest ocean depth is about 60,000 feet. On the radius of the globe, that is a trifle, but to *us* (could we see it all at once) would be an appalling abyss. Borings penetrate it to 5,736 feet, but the waste of anticlines (see Chapter VII) reveals its nature to a depth of many more thousands of feet. Its total thickness—that is, the depth to which materials like those of the visible rocks extend—is unknown, but seems unlikely to exceed 100 miles.

The Endosphere, or inner sphere, comprises the great bulk of the Planet, the name really denoting all which is within the Lithosphere. Very little indeed that can be regarded as certain is known about it. Efforts are frequently made, and may some day be successful, to deduce its nature from the principles of physics, but there are very few reliable data from which to reason. Its composition, its temperature, and its condition (whether solid, fluid, or gas, or all three) are not yet known.[1] Two points are certain. Its materials are nearly twice as heavy as those of the Lithosphere, approaching the specific gravity of iron. And it is magnetic, for it affects the magnetic needle of the compass.

Our subject is the Lithosphere. Unlike the Atmosphere and Hydrosphere, it is extremely diversified; and the extent of such parts as, not being covered by the Ocean are accessible to us is no less than 55,000,000 square miles, so that only a small proportion has yet been studied in detail; and even in such tracts research is more active than ever, so much is there yet to learn.

How do we interpret what we see? We do so in the light of processes which are going on at the present time; this is our criterion of judgment. While it may be admitted that other processes may once have prevailed, it is also certainly the case that no rocks have yet yielded any sign of such. The criterion has never failed us yet. To its employment we owe the science of Geology, now become a subject so great that no man knows more than a portion of it. Nevertheless, the reader need not be discouraged, for a grasp of its leading principles calls for no more than common-sense and a little intellectual persistence, so that exposition of past geological history would present no serious difficulty, but for one circumstance.

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[1] Consequently, theories concerning the origin of the Planet, such as the Nebular and Planetismal hypotheses, are as yet no more than hypotheses. In this book we shall not deal with them.

This circumstance is that we tend to think of what we see as rigid and abiding. Such changes in the configuration of hill and valley, land and water, as take place during the lifetime of any one man, are seldom noticed, or, if noticed, are regarded as mere local accidents, and their profound significance is missed. Thus, the topography comes, insensibly, to be thought of as permanent. Consequently, when we first attempt to trace out the geological history of any region, we are apt to assume that the familiar features were present all along.

Now, before we can interpret the geology of any country, this idea of permanency, which is a complete illusion, must be totally abandoned. No land-surface (as we shall presently see) can have existed for more than a short fraction of geological time.

Reading, for example, that marine shells are found in the rocks of Hampstead Hill or Snowdon, we may have said to ourselves: "Then Hampstead and Snowdon must have been beneath the sea." But when those shells were living, there was no Hampstead, there was no Snowdon; there was no Britain; the geography of the European area—nay, of the entire world—was quite different from what it is to-day. Geology is a record of unremitting change. The great rock-formations with which it has to deal convey an intelligible story only when we thoroughly realise that they were all accumulated under geographical conditions which have long since vanished.

To see the Lithosphere as it really is, we must envisage it as ever in process of transformation; as ever in motion, flexible, as rhythmically pulsating like a living thing.

On the one hand, Geology is unbending in its demand for evidence: it is a strict inductive science. On the other hand, both its evidence and its results are to be realised only by the imagination. To be a true geologist, accordingly, one must be able to see the world with penetrating and imaginative eyes; nay, with something akin to the vision of a poet.

## Chapter III

# What the Earth is Composed of

THE Atmosphere is composed of nitrogen, oxygen, and some other gases; the Hydrosphere, of water containing certain salts. The composition of the Endosphere is unknown.

The Lithosphere is, by definition, composed of rocks, but that statement raises at once the question : " What is a rock ? " Now, if we try to define by the familiar character of hardness, that fails us, for the same rock may be hard in one part and soft in another. But we can safely define a rock as an aggregate of mineral particles. Whereupon the reader will inevitably ask : " Then what is a mineral ? " To which the reply is : a substance of definite chemical composition, and with constant physical characters, occurring in the Lithosphere. It may also be well to add that most minerals are crystalline, a character of the first importance.

Solid matter is either crystalloid or colloid; familiar crystalloids being common salt and sugar, while jellies and glass are familiar colloids. While a crystal is growing, it will, unless interfered with by the growth of its neighbours, develop a regular mathematical form, with straight edges, flat lustrous faces, and angles between the faces which are always the same for each particular substance. Any one can verify this by dissolving a little salt in water in a glass dish, and letting the water slowly dry away, when the salt will crystallise in little cubes. But this beautiful form is the outward expression of an invisible internal structure, which is always there, even when the form is prevented from developing, and by which the nature of the mineral can be identified. One result of it is that the crystal splits much more easily in some directions than in others. Salt, for example, splits parallel to the faces of the cube. Another result is that light passing through the crystal undergoes remarkable modifications, such as refraction and often polarisation, our knowledge of which has, in recent years, been brought to a high degree of precision, and applied as follows. A slice is cut from a rock, so thin as to be transparent, and examined under a microscope with special optical fittings. The minerals can then be identified according to the manner in which they modify the light, thus revealing the composition of the rock.

Although 89 elements are now known to Chemistry,[1] about 98·5 per cent. of the Lithosphere is composed of the following eleven :—oxygen, silicon, aluminium, iron, calcium, magnesium, sodium, potassium, carbon, sulphur, and chlorine. A few elements (carbon in particular) are found uncombined. But nearly all minerals are compounds of two or more elements. Not mixtures of them. If we mix iron filings with powdered sulphur, we get a green dust, in which, however, a microscope will shew the grains of iron and sulphur lying side by side. But if we heat this *mixture* it changes into a dark mass in which no microscope will detect either iron or sulphur. That is a new substance: a *compound*. By suitable methods, nevertheless, the original weights of sulphur and iron can be recovered.

Again: more than 2,000 species of minerals are known, but only 14 of them enter, on a great scale, into the composition of the rocks of the Lithosphere.[2] In approximate order of abundance, they are :—Quartz (which is composed of silicon and oxygen); the Felspars, the Micas, the Hornblendes, Augite, Chlorite, Epidote, the Garnets, Kaolin, and Olivine; all of which are compounds of silicon and oxygen with one or more of the elements aluminium, iron, magnesium, calcium, sodium, and potassium. Magnetite and Hæmatite are compounds of iron and oxygen, Pyrite a compound of iron and sulphur, while Calcite is a compound of calcium, oxygen, and carbon. Most of them are coloured, and all of them crystallise in forms of gem-like beauty.

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[1] For the purposes of this book, an element can be regarded as a simple substance. We need not consider the recent researches into their disintegration.

[2] In this chapter the reader is requested to exercise a little patience, for here there is space only for a list, and a mere list of names is lifeless. But the reader can put life into it if he makes himself acquainted with the actual aspect of those minerals, which he can do in any good museum.

Of the rocks thus composed, more than 600 varieties are now recognised, but fortunately we shall need only to take note of 13; and these, moreover, fall into three great groups—the Igneous, the Sedimentary, and the Metamorphic. In igneous rocks, the minerals have crystallised where we now find them. The minerals of sedimentary rocks (with the exception of calcite) crystallised elsewhere, and have been brought together to form new aggregates. Metamorphic rocks were originally igneous or sedimentary, but have undergone re-crystallisation, sometimes partial, sometimes complete. The rocks themselves we shall consider in connexion with their several modes of origin. The purpose of this chapter is merely to give a general idea of the composition of the Lithosphere.

## CHAPTER IV

# Destructive Agencies

WE must now consider certain processes, by knowledge of which we can attain to a sound understanding of the nature and origin of rocks, and, through them, of the history of the Earth.

Most of us have, to our sorrow, experienced the effect of frost in bursting water-pipes. The same thing takes place "in Nature." Water finds its way down into the cracks of rocks, expands on freezing, and forces the sides of the crack asunder, so that when thaw comes the loosened fragments fall away. At the feet of crags we often see long trains of "scree," composed of angular blocks which have been detached in this manner. In the tropics, a similar effect is produced by the great difference of temperature between day and night, giving rise to rapidly alternating expansion and contraction.

But rocks disintegrate in another way. If we leave a piece of iron out-of-doors, it becomes converted into soft brown "rust," a compound of iron with the oxygen of the air which is dissolved in the rain. Now the exposed surface of a rock shews, if we break a piece off with a hammer, a soft crust of just the same nature, wherein minerals such as the felspars and others have decomposed, owing to the chemical action of the gases of the atmosphere. The products of decomposition, moreover, are soluble in water to a considerable extent, and are carried away invisibly in solution.

Rocks as hard as granites may decompose in this manner to depths of as much as 100 feet. Incidentally, this process, which is termed "weathering," is vital to us, for it is the decomposition of rocks which gives rise to soil. And without soil there could be no vegetable life upon the land, and, by consequence, no animal life.

Then comes the mechanical action of the Atmospheric water. Shattered and decomposed by the foregoing agencies, the loosened fragments are washed away by the falling rain and running rills—always downhill, never to return uphill again. Usually this process is gentle and slow, but sometimes violent and catastrophic. A sudden down-pour on a Welsh mountain in August, 1900, cut a channel 20 feet deep and moved blocks of 280 cubic feet. The dust and fragments are then washed down into the rivers, which roll and grind them into pebbles, sand, and mud. A river flowing at only two miles an hour will roll stones as big as an egg, and in flood will roll boulders weighing several tons. Armed with these as weapons, the rivers are ever cutting down and deepening, or, to employ the usual expression, "eroding," their channels, which are at the same time being widened by the wash of rain and rills. By the same agents, all the products of waste are, in the end, swept out to sea.

Glaciers also are agents of destruction. Snow, gathering on high mountains or in Polar regions, becomes compacted by re-crystallisation under the pressure of its own weight, and creeps down along the valleys as rivers of ice, the motion ranging from two feet per day in the Alps to 100 feet per day in Greenland. The thickness of the greater Alpine glaciers is about 900 feet, but those of Greenland attain to something like 5,000 feet. Blocks of stone become embedded in the bottom of the glacial stream, and, as the pressure of 1,000 feet of ice is 200 tons to the square yard, a glacier is a powerful eroding agent.

In the Pleistocene, Permian, and some other periods (see, for these terms, Chapter XII), enormous glaciers existed in many regions, such as our own country, where they cannot exist to-day. Features due to the erosive action of the Pleistocene glaciers are still conspicuous, besides which they have left great sheets of stony clay, ground off one part of a region and deposited in another. Several theories to account for these remarkable climatic revolutions have been put forward, but all of them are open to serious objections.

All the foregoing phenomena are effects of the Atmosphere upon the Lithosphere. Now we will glance at the effects of the Hydrosphere. Why is a coast so often a line of cliff ? In the open sea, the motion of any particle of water in a wave is vertical; but as a wave reaches the shallows near the shore, the motion becomes horizontal, and the water rolls against the land, hurling with it the blocks which have been falling from the hill, rounding them into pebbles, and cutting back the hill into a cliff. We can realise this when we listen in storm to

> the scream of a maddened beach dragged down by the wave.

The force of a breaking storm-wave is astonishing; indeed its impact may exceed three tons to the square foot. At Holyhead, in 1915, blocks weighing 100 tons were moved 35 feet horizontally in a single storm. Rivers cut for the most part vertically, but the sea, whose action is limited, from a little above high, to a little below low tide, attacks the land horizontally, and tends to cut it into a plain. Along the eastern coast of England, where the rocks are soft, the destruction in historic times has been considerable. In 1399, King Henry IV landed at the port of Ravenspur in Yorkshire, but the site of Ravenspur is now a mile out to sea.

Impressive as are these phenomena, we should note that, were cliffs cut back only by the sea, they would always overhang their base, for the sea has access to the base alone. Yet an over-hanging sea-cliff is rare; nearly all of them slope back upwards. Whence it is evident that less destruction is really effected by the breakers than by the quiet agents of the Atmosphere.

Thus we see that every land-surface is a scene of unremitting waste. Most of this is done so unobtrusively that we rarely notice it. But experiments made upon rivers which drain considerable areas give us a measure. Even the " silver-streaming Thames " carries off every year, from the surface of England, no less than 14,000,000 cubic feet of the substance of the land. This may be grasped by the imagination if we picture 14 cubes of rock, each of which is 100 feet long, 100 feet wide, and 100 feet high. But the Mississippi carries off, every year, from the surface of North America, no less than 7,468 cubes of the same dimensions. Some other rivers are even more destructive.

Finally, it is well to bear in mind that the whole of this process is, in the last resort, the work of the Sun. It is the Sun which, setting air in motion, raises waves upon the surface of the sea. It is the Sun which, melting ice in cracks or expanding cooled rocks rapidly, brings about disintegration. It is the Sun which, evaporating water from the surface of the Ocean, imports that vapour into the air, and thus eventually brings down rain and gives birth to rivers. But for the Sun, ocean would be dead calm, not a river would flow upon the land; all would be silent, still, and lifeless.

## CHAPTER V

# Constructive Agencies: Aqueous

PASSING to the agencies which build up new rocks, we will consider the Aqueous first, because they are an immediate sequel to the destructive atmospheric processes which were the subject of the preceding chapter.

For what becomes of the products of waste? We have already seen that, in the end, they all find their way to the sea. There, however, transport soon begins to be arrested, and the materials begin to be deposited. Pebbles, of course, are not carried far, so beds of shingle tend to fringe the shore. Sand can travel much farther; while fine muddy particles may be carried in suspension for hundreds of miles. The distribution of the wreckage of England can be seen any day along gently shelving parts of our coasts, such as Bridgwater Bay, the Dee-mouth, or the Wash, where at low tide there are banks of sand and mud extending for miles. Deposits of this kind, being insoluble in water, may be called Visible Sediment.

But the soluble and invisible products of waste, when reaching the sea, are taken up by various marine animals which build shells or frame-works composed of calcium carbonate or silica. These products, therefore, become visible also. Off the coast of Australia, corals have built-up a "reef" 1,200 miles long and 50 broad; while the calcareous ooze of the Atlantic, mainly composed of the shells of minute Foraminifera, extends over more than 40,000,000 square miles of ocean-floor. These deposits are called Organic Sediment.

Owing, however, to a variety of causes, deposition is not uniform. Mud comes at one time, sand at another, organisms flourish at a third, while there are pauses when nothing comes at all. Consequently, sedimentary deposits are laid down in distinct beds, or, as it is usually expressed, have a stratified arrangement. If we sprinkle some sand into a tumbler of water, let it settle, then some sand of another colour, let that settle, and so on, the sides of the tumbler will show a succession of strata.

The minerals of sedimentary deposits are, as we should expect, either those which do not readily decompose or those which are products of that decomposition. Sands are mainly composed of quartz and mica, muds of kaolin or colloidal clay, while the calcium carbonate of calcareous oozes tends, in time, to re-crystallise as calcite.

Deposits of this kind, still in process of accumulation, may be of great thickness. At Calcutta, New Orleans, and Venice, borings have pierced them to depths ranging from 400 to 600 feet without reaching their bottom. Now the pressure of 1,000 feet of sand or mud is about half a ton to the square inch. Such a pressure, maintained for thousands of years, drives the particles close together and makes the mass compact. In addition to which, slow chemical interchange goes on between some of the finer components, and cements the larger grains to one another. Thus a loose sand or soft ooze acquires the hardness which most of us associate with the term "rock." We then apply the following terms:—

| | | | | |
|---|---|---|---|---|
| Shingle, | when | hardened, | becomes a | Conglomerate |
| Sand | ,, | ,, | ,, | Sandstone or Grit |
| Mud | ,, | ,, | ,, | Shale |
| Calcareous Ooze | | ,, | ,, | Limestone |
| Vegetable Ooze | | ,, | ,, | Coal |

These are "Sedimentary Rocks." We meet with them far away from the sea, often at great heights above it. But they differ in no essential respect from water-borne deposits of the present day: differ merely in hardness and in the slight chemical changes alluded to.

They have the fragmental structure, the characteristic minerals, and the stratified arrangement of sedimentary deposits.

But they commonly contain a class of objects which are of the first importance. If we walk along a sandy sea-beach, it will not be long before we come upon shells, now embedded in the sand, but which were living not many days ago, just as many of the same kinds are living to-day on the sea-floor a few hundred yards away. Perhaps at the back of the beach there is a cliff of sandstone. We turn to look at it, and then we find that its beds also contain shells, not very unlike those of the sandy beach, but which we see at once to be remains of the animals which were living when the sandstone was being deposited. Examining them with a little more attention, we find that they are all of somewhat different kinds from those of the beach, whence it is evident that, at that time, the animals which inhabited the sea were different from those which inhabit it at present. If we come upon a limestone, we shall probably find still larger numbers of them. These organisms embedded in rocks are known as "fossils"; though there is no reason why we should not call a shell of the beach a "fossil" of to-day. In Chapter X we shall see that without a study of them we could never have known the marvellous history of the Earth-Life whereof we are a part.

In general, we may say that the Sedimentary Rocks are products of the Sun, setting in motion the destructive action of the Atmosphere, but born again as new rock by the constructive action of the Hydrosphere. From which, moreover, follows the further generalisation that, whereas the Land is the theatre of destruction, the Sea is the theatre of construction. Yet a great deal of the existing land is composed of sedimentary rocks: almost the whole of England, for example, is composed of them. One can travel from London to Dover, London to Exeter, London to Liverpool, London to York, and pass over nothing but sheets of ancient sediment. Which, again, tells us that the components of the Lithosphere are undergoing an unceasing round of transformation and re-distribution. So, as we turn our ears, we hear

> The moaning of the homeless sea,
> The sound of streams that, swift or slow
> Draw down Æonian hills, and sow
> The dust of continents to be.

## CHAPTER VI

# Constructive Agencies: Igneous

IN contrast to those which we have just considered, and which act upon the Lithosphere from without, Igneous constructive agencies act upon it from within, and their best-known phase is Volcanic Action. A volcano is popularly termed "a burning mountain," but it may not be a mountain, and it does not burn! To "burn" is to combine with oxygen, and volcanic heat is not derived from that source. Indeed, a far better simile is a ginger-beer bottle, the water in which contains gases in solution under pressure. The cork flies out with a report, followed by spray from liberation of the gas within the water, after which the water, full of bubbles, overflows at the neck of the bottle.

Steam and other gases, by reason of causes very imperfectly understood, concentrate at some place low down in the Lithosphere. They too are dissolved in a liquid under pressure, but that liquid is melted rock at a white heat, which owing to its gas-content is an explosive of the highest power. The direction of least resistance being upwards, this gas-laden fluid forces its way towards the surface, and presently blasts an opening with an explosion and a roar, hurling huge blocks of rock far into the air. This is a volcano, but it is not yet a mountain. At the same moment, by the explosion of its own contained steam, the molten rock is blown into clots and spray, which, as they cool, solidify to lumps of pumice and fine dust. The dust may be driven for many miles, and, mixed with the escaping steam, forms a dense black cloud which often makes day as dark as night. But

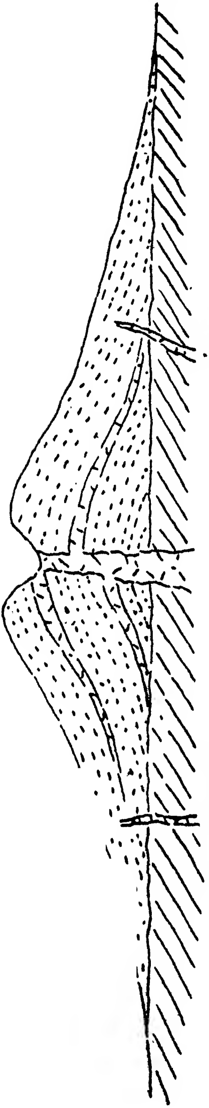

Fig. 1.—Section across a Volcano, composed of Tuffs and Lavas.

most of the fragments, falling back round the vent, begin to build up the characteristic volcanic cone (Fig. 1). Monte Nuovo, on the shore of the Bay of Baiae, was built up, in the year 1538, in 48 hours, to a height of 489 feet. Successive eruptions build up great mountains, such as Etna, 10,840 feet, or the gigantic cones of the Andes, which rise to more than 20,000 feet. As nothing can fall back into the vent until the explosions are waning, there is usually a hollow at the summit, known as the crater. Often, after the first stage, the molten rock itself, known as lava, flows out in streams, running down the flanks of the cone until its career is checked by cooling and consolidation. The fragmental products (miscalled "ash") are best known by the general name of "tuffs," and large volcanoes are usually composed of alternations of tuffs and lavas.

That volcanic action is not "burning" is evident when we learn that eruptions frequently break out beneath the sea, as happened in the Mediterranean in 1831, under 600 feet of water, the sub-marine cone being built up so as to emerge as a small island, called Graham's Island, which, however, was washed away to sea level in a few months. After a sub-marine eruption, ordinary sedimentation is resumed on the sea-floor, so that the tuffs and lavas become interbedded with the sediments. It is important to note that, whereas terrestrial cones are eventually destroyed by atmospheric waste, the products of sub-marine eruptions tend to be preserved, because the sea is the theatre of construction. To this circumstance, in the main, we owe the preservation of ancient lavas and tuffs, which are found in many regions. Western Britain, for example, though quiet since the Miocene Period (for which term see Chapter XII), is largely built up of volcanic rocks of some 15 different ages, and is thus one of the most volcanic countries in the world. But not a single cone survives; what we find being great beds of tuff and lava, most of which are interbedded with ancient marine strata.

What is a lava like after it has cooled? Well, anyone who has been to a glass-foundry and seen the molten glass run out in streams from the furnace will hardly be surprised to hear that the glass of our windows and tumblers is a sort of artificial lava. But if the material be allowed to cool slowly, it begins to crystallise, and is no longer wholly colloid. So, according to the same principle, the upper parts of a lava stream, which cool rapidly, consolidate as a natural glass. But, unless the stream be very thin, its inner portions have time to crystallise. They become, indeed, typical "igneous rocks," composed largely of augites, felspars, and other minerals; though there may be a little glass between the crystals.

Large reserves of lava, however, never escape from the vent at all, so when the eruptions are over they consolidate still more slowly, underground. Moreover, in their upward course, while still fluid, branches from them, known as "dykes," cut across the ordinary stratified rocks of the country (Fig. 1). Multitudes of these occur in Western Britain, laid bare by the waste of the beds among which they were originally concealed. Such dykes, as we should expect, are for the most part wholly crystalline. At still greater depths, there are enormous masses which take ages to consolidate, and that, moreover, under the pressure of thousands of feet of over-lying rock. Large crystals are then able to develop, and the product acquires the sparkling texture of a granite. Such a mass, laid bare by the waste of age after age, is the great granite of Dartmoor, which occupies more than 200 square miles.

To obtain clear ideas concerning any igneous rocks we may meet with, we need a natural classification. *First*, we arrange them according to chemical composition, which will give us two main classes ("A" and "C"). Class A contains a small proportion of silicon, but large proportions of magnesium, calcium, and iron. Class C contains a large proportion of silicon, but small proportions of magnesium, calcium, and iron. There is also a class (B) of intermediate composition. Aluminium, potassium, and sodium are almost always present. *Secondly*, we must divide each class according to crystalline texture, indicating either a rapid or a slow consolidation, near the surface or at a great depth, as we have just seen. Both principles are combined in this table.[1]

| | A | B | C |
|---|---|---|---|
| Superficial | Basalt | Andesite | Rhyolite |
| Deep-seated | Gabbro | Diorite | Granite. |

Thus, a rhyolite and a granite may have the same chemical composition; but, while rhyolite is superficial and largely glassy, a granite is deep-seated and wholly crystalline. Basalt and gabbro are dark, heavy, and weather (p. 11) with a rusty-brown crust because of their iron. Rhyolite and granite are not so heavy, are light in tint, and weather with a white crust because of their silicon. The composition of a tuff differs but little from that of the lava from whose explosion it is derived.

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[1] The reader is again requested to exercise a little patience, for, as in the case of the minerals (p. 9), these are mere names. To put life into them, specimens should be examined in some good museum.

The principal component-minerals are as follows:—

*Basalt*: Felspars, Augite, Olivine, Magnetite, Glass.
*Gabbro*: Felspars, Augite, Olivine, Magnetite.
*Andesite*: Felspars, Augite, Glass.
*Diorite*: Felspars, Augite, Hornblende.
*Rhyolite*: Quartz, Felspars, Glass.
*Granite*: Quartz, Felspars, Micas.

The destructiveness of volcanoes to man and his works is well known. In the year 79 C.E., Vesuvius buried the cities of Pompeii and Herculaneum under masses of tuff. On May 8, 1902, at 7.50 a.m., the Pelée volcano in Martinique broke out with a roar which was heard 100 miles away, and an avalanche of red-hot dust wiped out the city of St. Pierre, with its 30,000 inhabitants, in less than one minute. So, to class volcanoes as constructive agents may seem surprising. Yet not only do they contribute, both superficially and underground, to the structures of the Lithosphere, but they restore to the soil the precious alkalies (potassium and sodium) which, being incessantly washed away by atmospheric waste, are essential to the life of plants, and so of animals; and also restore to the air great quantities of carbon dioxide, which plants abstract and yet are always needing. Without volcanoes, possibly, the human race could never have existed. And they contribute also to the development of our higher faculties, for they provide us with inexhaustible delight in their exquisitely sparkling rocks, while their delicately curving cones are among the most beautiful of all the mountains in the world.

## CHAPTER VII

# The Disturbances of Rocks

HAVING thus gained a general picture of the components of the Lithosphere and of their origin, we may consider how they came into the positions in which we now find them.

Extensive lands, as we have seen, are often composed of sedimentary rocks of marine origin. Either, therefore, the sea must have sunk down or the land risen up. Such rocks must have been horizontal when deposited, so that, if the sea had merely shrunk away, they would still be horizontal. But, as we can see in countless exposures, they have almost always some degree of inclination, (known as their "dip"), thus revealing that it is the land which has moved.[1]

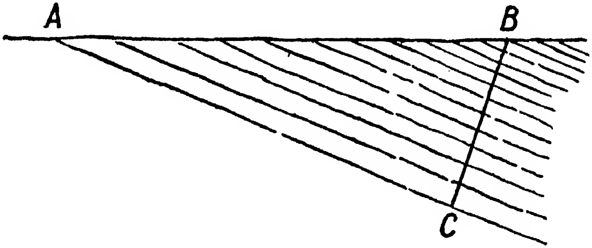

FIG. 2.—MEASUREMENT OF THICKNESS.

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[1] Thickness is measured from dip. If we have (Fig. 2) a series of inclined beds appearing along a horizontal surface AB, and produce their dip underground as AC, then a line BC at right angles to the dip is manifestly the thickness. This gives us a triangle ABC. We can measure the side AB at the surface, and the angle ACB is a right angle. By taking the angle of dip with a "clinometer," we can measure the angle CAB. Thus we know two angles and one side, and by trigonometrical methods can calculate the side BC, which is the thickness of the strata.

To realise the general meaning of dip, let us traverse, from north to south, an imaginary country (Fig. 3). For some miles the beds dip southwards, but after an interval at "Syn" they dip northwards, and after another interval at "Ant" they dip southwards again. Examining the intervals, we find that the dip grows gentler as we approach them, and becomes horizontal in the middle of each interval. If we try to draw this, we find we are drawing curves. Dip, then, is part of large curvature or folding. In cases such as the foregoing we have to infer it; but folding is to be seen on hundreds of cliffs. The fold at "Syn" is called a syncline, the fold at "Ant" is called an anticline.[1]

Rocks, then, have been folded. That they were often quite "hard" when this happened is certain, from many kinds of evidence. Lavas, for example, which must have consolidated quickly, are often folded along with the beds between which they lie. Of course rock-folding is impossible at or near the surface. Under the powerful pressures, however, available in engineering works, many substances commonly regarded as rigid can be rendered plastic. Now consider an imaginary cube of rock at a great depth. The overlying load is far more than sufficient to crush it; yet, being supported on all sides, it has no room to crush. Consequently, it becomes plastic, and can yield to any

South
Ant
Syn
North

FIG. 3.—ORDINARY FOLDING.

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[1] How the folding-stresses originated is a problem which is still under investigation.

force, so that if it be stratified its beds can fold.

How was the folding force applied? Folds such as those in Fig. 3 look as if they might be due to simple elevation in one part and subsidence in another, but they could equally be produced by forces applied laterally, and there is abundant evidence that they were produced in that manner. Let the reader lay a thin door-mat on a table, and, placing a hand on each end, slowly push his hands towards each other. The mat will buckle up into a series of folds. Besides, there are folds like those in Fig. 4, which could have been produced only by forces acting horizontally, and hundreds of such can be seen in many regions. It is worth noting that in over-driven folds of this kind the beds on the middle portion are turned upside-down. Folds exist on all scales from the microscopic to such as are measured in many thousands of feet.

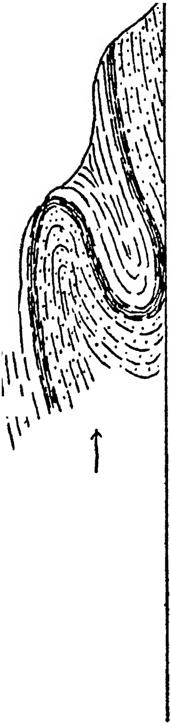

Fig. 4.—Over-driven Fold.
Arrow indicates direction of force.

Ruptures (which are rarely gaping fissures) may be regarded as incidental to folds. A very common kind, known as a "Fault," is approximately vertical, the beds being shifted up on one side and down on the other.[1] A more interesting kind results from excess of strain on an over-driven fold, whereby the middle arm is torn out, and the upper arm carried forward so as to over-ride the lower (Fig. 5). This, which is known as a thrust-plane, is powerfully compressive. The range of magnitude in ruptures corresponds with that in folds, the "Moine" thrust-plane in the North-west Highlands having an over-drive of at least 10 miles.[1]

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[1] Cracks without any displacement, which are called "Joints," are numerous in hard rocks of all kinds, and are often very conspicuous. They are probably due to shrinkage—in sedimentary rocks during drying, in igneous rocks during cooling. But some may be due to tension or torsion.

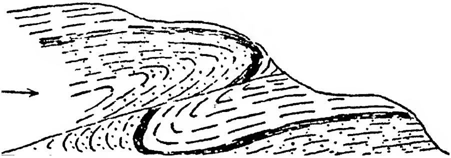

FIG. 5.—THRUST-PLANE.
Arrow indicates direction of force.

In some tracts, such as the Alpine chain—as well as certain regions now worn down to plains, which are the wrecks of ancient mountain-chains—folding, especially of the over-driven type, is developed on a very grand scale, and accompanied by minor folding of excessive intricacy.

[1] Earthquakes are not of much importance as agents of change, being, rather, effects of such agents. Rupture deals a shock underground, and originates a wave of compression which travels out from the centre in all directions. On reaching the surface, it becomes an ordinary wave of vibration which travels out in circles, as when a stone is thrown on to water. The range of motion of any given particle of rock is surprisingly small, rarely exceeding a few inches, even in great earthquakes. The terrible destructiveness of the shock appears to be due to its high speed of propagation, which may exceed a mile in a second. And earthquakes would hardly be formidable to Man did he not live in stone buildings.

## CHAPTER VIII

# Some Effects of Disturbance

In this Chapter are brought together certain phenomena which, though of different kinds, are all in one way or another effects of disturbance.

*Unconformity.* In an ordinary sedimentary succession, each bed lies flat upon the upper surface of its predecessor, to which it is then said to be "conformable." Let us suppose such a succession to be folded, then shaved off by atmospheric and marine erosion, and then subside again beneath the sea, so that another sedimentary series is deposited upon it (Fig. 6). The new series will in this case rest upon the worn and upturned edges of the older one, to which it is then said to be "unconformable." It will be seen that an unconformable junction must always represent a considerable, often a very great interval of time.

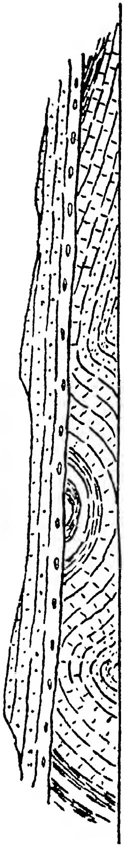

FIG. 6.—UNCONFORMITY.

*Slaty Cleavage.* When folded beds are very tightly packed, their particles become flattened in a direction at right angles to that in which the folding-force is applied, and, as the latter is usually horizontal, the flattening is usually vertical. This develops a new series of divisional planes, known as a cleavage, along which the rock splits more easily than along the original bedding, which the cleavage may cross at any angle (Fig. 7). The rock is then a slate. The well-known roofing slates of North Wales and other districts were fine mudstones which were subjected to a very powerful and evenly applied pressure. Sandstones are but feebly susceptible of cleavage. A curious piece of evidence as to the nature of the process is that fossils in slates become grotesquely squeezed out of their original shapes.

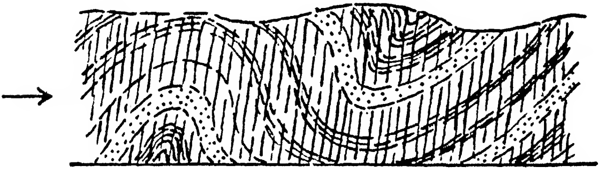

Fig. 7.—Slaty Cleavage crossing Folded Bedding.
Arrows indicate directions of force.

*Metamorphism.* Under the stress of powerful thrusting, minor folds are torn-out, and their disrupted arms driven over one another, so that for miles we may see nothing but overlapping thin-edged strips. At greater depths this is impossible, but a far more wonderful process takes its place. Resistance being excessive, the energy of the impulse is transformed into what, for lack of a real understanding of the phenomenon, we call molecular activity. Such conditions being quite unlike those in which the minerals were formed, the chemical stability of many of them is upset, and their elements begin to enter into new combinations,[1] which are chemically stable under the new conditions. For example, the elements of augite re-crystallise as hornblende, those of the felspars re-crystallise as white micas. These are simple cases, most of the chemical reactions being more complex. It is noteworthy that, whereas at lesser depths we find crushing and breaking down, under these conditions there is no sign of crushing, but only of transformation and crystalline re-building.

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[1] Somewhat similar changes take place in sedimentary rocks under the influence of the heat emanating from granites and other large masses of deep-seated igneous rock, but the effects rarely extend far from the margin of the granite.

The new crystals, however, owing to the great stresses, have not equal freedom of growth in all directions. The problem which they present is not, indeed, one on which we have as yet much guidance from experiment; but it is clear that the direction of least resistance is that of the gliding and stretching which are going on in the mass, for in that direction, at any rate, their principal growth does take place. Thus, their growth tends to make them lie parallel to one another, and this imparts to the whole rock a parallel structure, known as "foliation" or "schistosity." In virtue of the fact that their characters are an outcome of change, these rocks are termed "metamorphic," and in virtue of their structures and their crystallisation they are termed "crystalline schists."

The process may affect any rock, whether igneous or sedimentary, and, according to its measure of intensity, may partially or totally obliterate the original structures. A basalt is transformed into a hornblende-schist, a rhyolite or a granite into a mica-schist, a sandstone into a quartzose-schist, a shale into a different variety of mica-schist, a limestone (if not quite pure calcium carbonate) into a schistose marble.

At the highest stages, which are imperfectly understood, the process is complicated by igneous action, for the schist becomes permeated by granite, innumerable thin seams of which develop along the planes of foliation, thus giving rise to a banded structure that simulates, but is totally different in origin from stratification. Such rocks are known as Gneisses.

A rock may be affected by metamorphism along narrow zones only, but in such cases the metamorphic products are usually of a low order. In many parts of the world, on the contrary, true crystalline schists occupy regions of thousands of square miles. In Britain, our largest region of the kind is the Scottish Highlands, but it is probably a portion of a far larger tract, extending at least from Ireland to Scandinavia.

The crystalline schists present one of the most difficult (and the most fascinating) problems of geology. Where their structures have been most carefully studied, they are found to have been folded in the most complicated manner. Their more fissile members are full of corrugations so minute as to be perceptible only under the microscope, while their greater folds are on the grandest scale, being believed, indeed, by some of their closest investigators to have a horizontal extent measurable in scores of miles. If we stand before a crag of mica-schist, it seems almost alive with motion, while with the glitter of its crystals in the sun few things exceed it in beauty.

## CHAPTER IX

# The Evolution of Land-Surfaces

FOR most persons, probably, the features of a familiar landscape are such a matter of course that they never pause to ask themselves the question of how those features came into being. Probably the very idea of origin has never occurred to them at all. The landscape merely seems part of the established order of things, which has always existed and always will exist. But when once we begin to think geologically, the problem not only arises but becomes one of the most fascinating which the science presents. It can be simplified a little, for we can make a general division into features due to accumulation and features due to waste.

The only features of accumulation which attain to mountainous dimensions are volcanic cones. Others of the class are the hummocky moraines left by glaciers, and the more familiar sand-dunes built-up by wind. The dunes which fringe our sea-bays are moderate both in extent and height, but in deserts like those of Central Asia dunes cover vast areas and attain to as much as 600 feet in height. Flat tracts of alluvial silt are also extensive along the valleys of large rivers.

But by far the greater part of the features of the land are Features of Waste. The process of waste in itself we studied in Chapter IV; we have now to consider the manner in which it develops the features of a landscape. To minimise complications, let us suppose the process applied, at the outset, to a surface with the least possible diversity—that is, to a plain. At sea-level, of course, the process cannot come into operation, because there must be a slope for the running of water, so we will suppose that our plain has been raised to a height of several hundred feet and has become a plateau. We will also suppose that it has been raised a few feet higher along a central axis than it has elsewhere, so as to be an exceedingly gentle but oval dome. Nor is any plain ever perfectly smooth; there are always irregularities, even if so slight as to be imperceptible.

Then rain falls upon it, and the process we sketched out in Chapter IV begins. Running down the slopes, the water finds for itself channels, and, once found, it keeps to them. Cutting them down, it deepens them; cutting back towards their heads, it makes them longer; while at the same time, running down their sides, it widens them, till tributary streams come in and join the rivers. Thus our plateau is being dissected, and has become a hill and valley country. Not a single valley is a sinking-down or gaping-open; every one of them is an excavation, cut-out by the river which flows along its bottom. What, then, are the hills? Not one of them has been upraised; they are simply and solely the great intervening masses which are left. Nor are they left to stand out for ever. They too are but a stage in the process: not a moment passes but they are yielding to it; their ultimate doom is written in their very forms.

If the plateau be of moderate elevation, the region becomes an undulating lowland. If it be lofty, it is carved into a mountain-land, such as our own Wales or Scottish Highlands. That such a process can have given us the deep valleys and lofty summits of Scotland or Snowdonia may be difficult of belief; but there is a notable case which removes that difficulty the moment we consider it. The river Colorado in the west of North America rises in mountains where there is a rainfall. But on its way to the Pacific Ocean it has to traverse a desert plateau in which, though the river goes on cutting down, there is no rain to wash off the sides and widen the valley. The astonishing result is that the Colorado now runs for 300 miles in a ravine, known as the "Grand Canyon," with vertical sides and 3,000 to 5,000 feet in depth (Fig. 8), while its numerous tributaries all run in ravines of the same character. Moreover, it happens that the beds whereof the plateau is composed remain horizontal over most of the region, so that bed can be seen to match bed on the opposite cliffs of the ravine, and to wind round into the lateral gorges without interruption, leaving no doubt whatever that the whole amazing system has been carved out by the Colorado and its tributaries. But the Grand Canyon of the Colorado is deeper than the valley of any British river, which makes it quite easy to realise that our British mountain-lands have been sculptured by the same process.

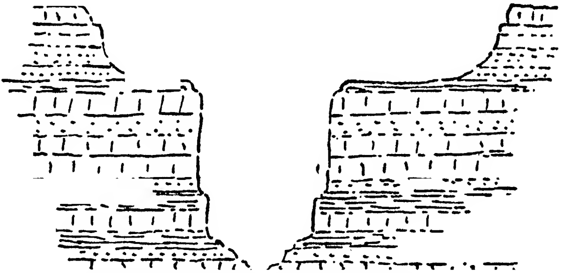


FIG. 8.—SECTION ACROSS THE GRAND CANYON OF THE COLORADO.

*Folding and Feature.* It is important to bear in mind that we must not expect to see large folds in their entirety, for atmospheric waste is far too potent. We do not find anticlines rising as round-backed ridges, for no sooner does an anticline begin to form than its upper parts, becoming exposed to waste, begin to be swept away. Indeed, owing to a combination of causes, anticlines are peculiarly apt to weather into valleys, while synclines commonly give rise to hills, the reverse of what might have been expected (Fig. 3). Snowdon, the loftiest mountain in England and Wales, is carved out of a deep syncline. It may be observed, in this connexion, that the waste of anticlines affords us access to rocks which elsewhere lie deeply buried (Fig. 3).

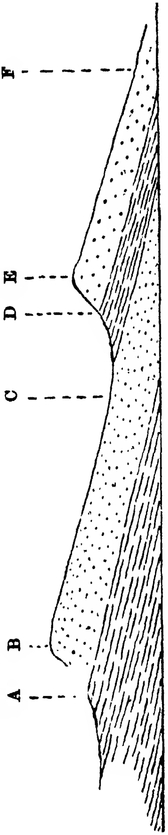
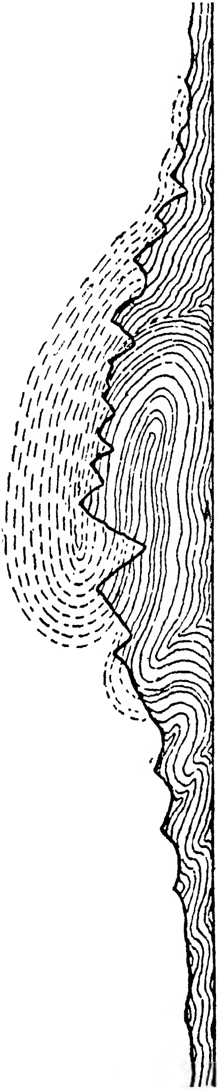


FIG. 9.—ESCARPMENT AND DIP-SLOPE.

Attention may be drawn to a type of feature produced by erosion which is so extremely prevalent that it is certain to be met with by the reader. On the flanks of anticlines or synclines, where the beds of course have a dip, the ridges of hard and resistant rock acquire the peculiar forms shewn in Fig. 9, where the gentle inclines BC and EF are called Dip-slopes, and the steep cliffs AB and DE are called Escarpments. A fine example of a mountain-escarpment is the great northern crag of Cader Idris. A far lower but far longer one is the escarpment of the Chalk, which (with an interruption at the Wash) runs all through England from the coast of Yorkshire to the coast of Dorset. It is very pronounced where it is crossed by the London Midland and Scottish railway near Tring station.

The relation between folding and feature may be summarised as follows. Elevation is essential to erosion, because without differences of level water could not run. Thus, the part played by elevation is to give erosion its opportunity. Folding, since it compresses beds into a smaller space than they occupied when horizontal, gives rise to elevation. But the features developed out of the folded masses thus elevated are the work of erosion and erosion only.

*Mountain - Chains.* These are special and exceptional features, quite unlike our broad British mountain-lands, a chain being always narrow in proportion to its length, which is often very great. Considered as a whole, the loftiness of a mountain-chain is due not to erosion, but to movement, which has ridged-up a narrow zone, or a series of over-lapping parallel zones. But the individual mountains of a chain are just as truly the work of erosion as any other mountains. The ridges of elevation, being subject to waste in the ordinary manner, became sculptured into ranges of lofty peaks. The Alps as a whole are a series of parallel ridges due to movement; but the Jungfrau and the Matterhorn have been sculptured out of those ridges by atmospheric waste. With regard to the nature of the elevating movements we have much to learn. In the Alps, which have been long and carefully studied, it is without doubt folding of the over-driven type (p. 26) on a gigantic scale and extremely complex (Fig. 10). Folding is known to be



IG. 10.—Diagrammatic Section across a Simple Mountain-Chain.

line represents the erosion-forms of the mountains. The broken lines in the air represer such parts of the folds as have been worn away.

present in other chains, but our information is as yet very scanty. Of the real structure of the two greatest chains in the world, the Himalayas and the Andes, next to nothing is yet known.

*The Evanescence of Land-Surfaces.* But the finger of Fate is on the mightiest of mountain-chains. The very same powers which have carved it into majesty are destroying it night and day, without remission, and a time is, geologically speaking, not far distant when every vestige of those white peaks will be sleeping upon the bottom of the ocean. Again and again has this taken place: tracts which are now quite low have Alpine structures, and are the worn-down roots of vanished mountains of old time. The combined effect of the destructive agents is to reduce every country to a plain at sea-level. In fact, but for the counteractive effects of the movements of the Lithosphere, all the land in the world would, at the present rate of waste (p. 14), be swept down into the sea in some five or six million years, and that is but a small fraction of geologic time. A land-surface, accordingly, is but a passing and fleeting phase of Change.

The hills are shadows, and they flow
  From form to form, and nothing stands;
  They melt like mists, the solid lands,
Like clouds they shape themselves and go.

*The Rhythmic Cycle.* Combining what we have now learnt, we are able to discern a general principle. Forces acting horizontally build up folded structures. This results in elevation, and brings in terrestrial conditions. But with terrestrial conditions erosion is inevitable, and the lands thus born are swept away. The products of that waste, in their turn, become accumulations of new sedimentary rock on the floors of the adjacent subsiding ocean basins. And these accumulations provide material with which horizontal forces, breaking out again, are able to build up folded structure, and repeat the whole series of phenomena. Thus there is a rhythmically recurring cycle of geologic transformation.

## CHAPTER X

# Sequence of Events in Time

SO far, we have done nothing to introduce the idea of Order in Time into our view of these phenomena. That idea is obtained by geological science from the sedimentary rocks, according to a very simple principle. In any succession of sedimentary rocks, it is obvious that the lowest bed, having been deposited first, is the oldest, and so on in order upwards; a principle which is known as the Law of Superposition. All our ideas concerning geological chronology are based upon this law.

Where the beds are horizontal the order of superposition is of course quite easy to ascertain; but in that case the thickness we could see in any country would be no greater than the height of its highest hill, which might be quite small. Fortunately, disturbance and erosion come to our aid, for we obtain access to older beds in the cores of wasted anticlines (Fig. 3). Further: exposures may be isolated, but if in one of them we have beds 1, 2, 3, 4, and in another beds 3, 4, 5, 6, we can see that beds 5 and 6 are a continuation of the series; and so, if the beds have a dip (Fig. 2), we have access to a great thickness of them in quite a low country.

But in applications of the law over wide areas we encounter a serious difficulty. At the present day, we know that sand may be laid down on one part of a sea-floor, mud on another, limestone on another, and yet the three deposits are contemporaneous. Among old sedimentary rocks, a bed may be seen to change its character if we can follow it for some distance along a clear section. Therefore, when attempting to correlate beds in separated areas, as between the north and south of England, we may fail to discern that a sandstone in the north is contemporaneous with a limestone in the south; or we may take similar beds to be contemporaneous which are really of different ages. Again: we may have determined a succession in Britain and a succession in America; but how are we to establish any correspondence between the two? Thus, had we to depend upon superposition alone, without the aid of any other principle, a general history of the Earth would be unattainable.

Here, fortunately, we have the assistance of one of the greatest discoveries ever made. William Smith, an engineer and surveyor, was sent to Bath for the construction of a canal in 1793. The succession of beds at Bath is clear and simple, and the rocks are full of fossils. Smith made collections, and by 1796 had discovered that, while some fossils ranged through a considerable part of that succession, there were certain other fossils which were confined to certain beds, and never found above or below them. After this, he travelled for many years throughout England and Wales, in search of further evidence upon the question. Smith's Principle, which is that certain fossils are found in certain beds, and only in those beds, never in underlying or overlying beds, has since been tested innumerable times, and always found to hold good.

The principle enables us to overcome the difficulty presented by changes in composition of strata, if we find that the sequence among the fossil-assemblages remains the same. In like manner, it enables us to establish correspondence between ascertained successions in widely separated regions, as between Britain and America. Again, when we come upon some bed whose place in the general order cannot be ascertained by superposition, then, if it contain fossils whose place in that order is known in regions where the sequence is clear, we are able to infer the age of the isolated bed.

But it must never be forgotten that the principle itself rests upon the Law of Superposition. For no fossil can be employed to establish a correspondence unless its position in an unequivocal sequence of strata has been ascertained.

And it has been ascertained, through many years of research, that the major fossil-assemblages do occur, all the world over, in the same order of sequence. Thus, a general history of the Planet has become attainable. If the magnitude of a discovery be estimated by what it has made possible, then Smith's discovery, opening to us the depths of Time, ranks with those of Galileo, Newton, Dalton, or Darwin.

## CHAPTER XI

# Life and Time

BUT Smith's discovery also opens to us the Book of the History of Life. Let us now consider, not the strata, but the fossils themselves. As we recede in time, species[1] of plants and animals which are still living grow fewer and fewer, and after a while disappear, so that in older formations, all the fossils belong to species which are now extinct. More than 100,000 extinct species are now known. Smith's Principle tells us that each such species had a life duration, had a beginning and a dying-out, and reveals to us a general succession among all forms of Life.

When we try to characterise the nature of the change from earlier to later forms, we are apt to say that it is from lower to higher; but that is a sentiment, a judgment of our own. What we do find is (1) increasing differentiation of parts, (2) increasing specialisation of function, and (3) divergence of type, so that ancient forms are intermediate in character between existing forms.

In Smith's day, and for half-a-century afterwards, geologists regarded species as quite independent of each other. But though extinct species are less and less like living ones as we recede into the past, yet they are not utterly unlike, but they all bear some resemblance to one another and to living species. The record, however, owing to a variety of causes, is exceedingly imperfect, considered as a whole. But in strata deposited under specially steady conditions, as in clear and open sea, it may be free from interruptions. Such a formation is the English Chalk, and it is rich in Echinoderms (*i.e.* sea-urchins), one genus (*i.e.* major division) of which includes six species. Each of these is confined to certain beds, below or above which it is never found. On the Kentish coast the six species are distributed through a thickness of some 200–300 feet of Chalk. These beds were drastically searched throughout, and 2,000 specimens were obtained, a note being taken of the precise position of each specimen. When they were carefully studied, it was found that, proceeding from the bottom to the top of that succession of beds, there was a steady and unbroken change from Species No. 1 to Species No. 6, and that the change took place in every one of the 18 different parts of the shell. Similar studies have since been made of other kinds of marine fossils, in other formations, and with similar results. But a continuous change is a development: it is an Evolution. This then is the true explanation, the real inner meaning of Smith's Principle. The history of life on the Earth is the history of an evolution. Species are past our numbering, but Life is One.

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[1] The term "species" is notoriously difficult to define, but, as we must be brief, the following must suffice. All individuals, of Plants or Animals, which are alike in their essential characters, constitute a species. Thus: among the many kinds of Cats, all Lions belong to one species, all domestic cats to another species.

## CHAPTER XII

# Geological History

IN order to make the evidence furnished by the sedimentary rocks available for historical purposes, they have been divided into 15 major formations, termed "Systems," corresponding to 15 principal successive periods. The following table shews these systems, arranged on the page in ascending order from the oldest upwards. Its right-hand column shews the periods in which certain leading types of Life are first known to appear. The zoological terms employed in it will be explained on p. 46 :—

| GROUPS OF SYSTEMS. | SYSTEMS. | FIRST KNOWN APPEARANCES. |
|---|---|---|
| NEOZOIC . | Holocene. | |
| | Pleistocene. | Man. |
| | Pliocene. | Man ? |
| | Miocene. | Anthropoid Apes. |
| | Oligocene. | |
| | Eocene. | Placental Mammalia. First Still-living Species. |
| MESOZOIC . | Cretaceous. | Flowering Plants. |
| | Jurassic | Birds. |
| | Triassic. | Non-Placental Mammalia. |
| PALÆOZOIC | Permian. | Reptiles. |
| | Carboniferous. | Amphibia. |
| | Devonian. | |
| | Silurian. | First Vertebrates (Fishes). |
| | Ordovician. | First Land Plants and Animals (Insects). |
| | Cambrian. | Brachiopoda, Lamellibranchiata, Crustacea. |
| PRE-CAMBRIAN SYSTEMS. | | Sea-Plants ( ?), Sponges, Worms. |

As will be expected from the preceding Chapter, the systems are defined, not by the nature of their component rocks, which may be different in different districts, but by the characters of their fossils. A stratigraphical system is a series of strata which contain a given fossil-assemblage.[1] We find, for example, in America, beds containing a fossil-assemblage like that of the Ordovician of Britain, and moreover that, as in Britain, they are underlain by beds with an assemblage of Cambrian, and overlain by beds with an assemblage of Silurian type. That is what is meant by saying that those three systems occur in America. The chronological order of the systems, as determined by superposition, is the same all over the world.

Every system is not found everywhere : it may have been locally swept away by waste, or may never have been deposited there at all. There is no doubt that the Chalk once extended over the whole of what is now the south-east of England, but it has been swept away from the district called the Weald of Kent and Surrey. On the other hand, no Holocene beds are being laid down on the summits of the Surrey hills : the Holocene system is absent there. Again, the systems and periods are not marked off sharply from each other, any more than the "Middle Ages" are sharply marked off from the period which we call the "Renaissance." In England there is a sudden change from Cretaceous to Eocene, but in some countries a gradual transition is found. Sudden breaks occur at unconformities, but from the general order of the systems we know what formations are missing in such cases. As for igneous rocks, they can be dated in accordance with their relations to sedimentary rocks of ascertained position.

The systems, in their turn, fall into three great natural groups, according to their general types of life. Those of the Palæozoic (Greek, "palæo" = ancient, "zoe" = life) are the most primitive and remote in character; those of the Mesozoic ("meso" = middle) of an intermediate character; while those of the Neozoic ("neo" = new)[1] begin to be of modern types. In the course of evolution, every Palæozoic and Mesozoic species has become extinct; and so have many of the Neozoic, but a few still-existing species appear for the first time in the Eocene, the proportion increasing until the present stage of the Holocene, when, in the nature of the case, all species are still surviving forms.

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[1] The names are founded on various considerations. Better ones can be imagined, and will probably some day be devised. "Holocene" is a name lately come into vogue for the formations which used to be merely termed "Recent."

For the fossils which are special to the several systems larger works must be consulted. Here there is space only for a few explanations of the right-hand column in the table of Systems. Perhaps it may be well to remark that as the land is the theatre of destruction, the sea of construction and preservation, the great majority of fossils are marine forms. Also, that all known forms of Life are divided into a Vegetable and an Animal Kingdom, so that every organism which is not a Plant is an Animal.

The first well-defined forms are those found in the Cambrian System, and they are all marine. Crustacea are animals with jointed armour, of which the modern lobster and shrimp are well known to us. Lamellibranchiata are "shell-fish," of which the cockle and the mussel are familiar. Brachiopoda resemble Lamellibranchiata externally, but differ anatomically, and are more primitive. Vertebrated animals are those with a spinal column or "back-bone." Amphibia are still represented by the frogs and toads. Mammalia are vertebrates which nourish their young by mammæ or breasts. The Non-placental are the Lower Mammalia, still represented by the kangaroos. The first birds had teeth on their beaks, and were allied to the reptiles. The Placental Mammalia include all those which are familiar to us. The "anthropoid" are the man-like apes, including the chimpanzee. Whether a species which can be termed "Man" existed in the Pliocene period is at present under discussion, but evidence for that view seems to be accumulating. His existence in the Pleistocene period is abundantly demonstrated.

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[1] Often called Cainozoic ("kaino" = new) or "Tertiary."

It should be noted that the column shows only *first* appearances. For every one of the great inclusive groups given in the column is still in existence. Also: to bring out the phenomenon of extinction, sub-divisions of these groups would be needed. Nor does the column give any idea of relative abundance at different times. For example: the Brachiopoda, now very rare, were wonderfully numerous during Palæozoic times; while the Lamellibranchiata, rare in Palæozoic rocks, become abundant in Mesozoic, and extremely abundant in Neozoic rocks. Birds are always rare as fossils. The Mammalia are rare until we reach the Eocene System. Apes are never plentiful, and, though tools of Man are numerous, his bones are rare.

As an example of how the systems are employed, let us suppose that we are exploring a country hitherto unknown, and that (Fig. 11) we find sedimentary rocks in it. We observe, of course, the nature of the rocks, and we determine the order of superposition. We find a conformable

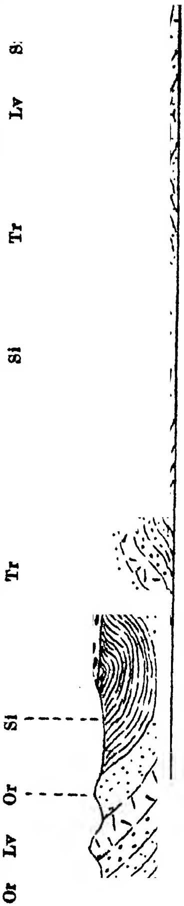

FIG. 11.—SECTION ACROSS A COUNTRY COMPOSED OF THREE SYSTEMS.
Or = Ordovician, Si = Silurian, Lv = Lava, Tr = Triassic.

series, folded, and then we find patches of another series dipping at very gentle angles, and resting unconformably on the first. We look for fossils and find them. Those in the lower members of the first series prove to be of Ordovician, and those in its upper members to be of Silurian type. In the second series we find fossils of Triassic type. So we know at once that the Devonian, Carboniferous, and Permian systems are missing. Somewhere in those three periods, the older rocks were folded and eroded, then let down and sediments deposited upon their edges in Triassic times; while, finally, the whole mass was again gently raised and again eroded, reducing the Triassic rocks to mere patches. If, between the Ordovician beds, we find a lava, we know that volcanic action broke out in the course of Ordovician time in that region. If we can show that there was a tract where one of the systems was never deposited at all, we infer that, in that interval, the said tract was not submerged, and may be able to gain some idea of the distribution of land and water in that period: may be able to restore, if vaguely, geographical conditions which have long since passed away.

Usually, however, the reader will find himself in a country whereof a good deal is already known. If, then, he obtain a geological map, showing, in colours, the formations which are visible at the surface, he will find that country far more intelligible and interesting. Geikie's map of England and Wales, on the scale of 10 miles to the inch, will probably suffice for most of those who use this book. For a country in which the reader is making a long stay, still more for the country wherein he resides, he should obtain the map-sheet of the Geological Survey, on the scale of one inch to one mile.

Thus, all events are referred to these systems. From a study of them, we are slowly reconstructing a connected history of the world. But even in the best known regions, such as Britain, our knowledge of that history is very far indeed from perfect.

*The Age of the Earth.* A word will be expected on the subject of Geological Time. This is not known with any approach to precision, but was without doubt immense, and (as is astronomical space) far too great for the mind to realise. The calculations of Kelvin and Tait that it could not exceed 20 or even 10 million years broke down with the discovery of radio-activity. Lately, from studies in radio-activity itself—that is, from the rate of change in certain radio-active minerals contained in certain rocks—estimates of the order of more than a thousand million years have been suggested; but, as the method is in its infancy, judgment must be reserved. Not because the estimates are likely to be too high: they may just as likely be too low. Indeed, recent physics and stellar astronomy suggest a lapse of time ranging up to 10,000 million years. Geological estimates, based mainly on thicknesses of strata—in other words, upon the work done by the Sun upon the surface of the planet, are of a similar order of magnitude to the foregoing. The Palæozoic rocks have long been known to be of enormous thickness. But the Mesozoic and Neozoic systems were grossly under-estimated, owing to the fact that the British representatives of those systems are attentuated developments. Their thickness in other parts of the world is now known to be quite comparable to that of the Palæozoic rocks. The total thickness of the systems, from the base of the Cambrian upwards, appears to approach 200,000 feet.[1] It may be an aid to the imagination to mention that the stupendous folding and erosion of the Alps dates from so relatively recent a time as the beginning of the Miocene period; that the erosion of the Scottish Highlands is of the same general age, and that the great volcanic cone of Etna, nearly 11,000 feet in height, has been built up by successive eruptions since the later part of the Pliocene period. Yet (p. 44) even the

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[1] Computed from the measurements quoted in Sir Arch. Geikie's Text-Book, ed. 1903. Later measurements for the whole series do not seem to be available.

Miocene is as yesterday compared with the Cambrian period.

*The Mystery of the Early Ages.* The Cambrian fossils are tolerably well-organised animals, and of widely divergent types, thus indicating that they are products of a prolonged evolution. Five or six Pre-Cambrian systems are now known, and there may be as many more. They are of great thickness, and separated by unconformities of unknown magnitude. Therefore it is clear that Pre-Cambrian time was of enormous length. Some think it may have been as long as the whole of the subsequent periods put together. Fossils have been found, but they are scanty, and rarely well enough preserved for their species to be determined with precision. They tell us, indeed, little more than that certain types of Life were already in existence. At last, then, Smith's Principle cannot be employed.

Consequently we are, at present, without any means of correlating the Pre-Cambrian systems of one country with those of another.

Moreover, even within the limits of a single country, it is often exceedingly difficult to ascertain the true order of Superposition, on account of the complex and gigantic folding which these ancient rocks are found to have undergone in the districts which have been most closely investigated. Besides which, our perplexities are greatly aggravated (though the interest of the problems is as greatly enhanced) by the fact that the folding has frequently been of the kind which induces regional metamorphism, so that we do not always know the original nature of the rocks themselves.

Nor do we find any trace of a Beginning. In region after region, a sedimentary component speaks of derivation from the waste of a Something even more remote

> In the dark backward and abysm of Time.

APPENDIX I

# Notes on the Figures

ALL the figures are "sections"—that is, they represent what would be seen if a vertical cut, something like a magnified railway cutting, were made through the country. Different kinds of shading are employed to represent the different beds of rock.

*Fig.* 1. *Section across a Volcano.* The volcano has broken through the ordinary stratified rocks of the country. Most of the cone is composed of tuffs, but lava is shewn in the "throat," from which proceed three streams of lava, which flowed out before the cone had grown to its present height. Two dykes which never reached the surface are also shewn.

*Fig.* 2. *Measurement of Thickness.* This is a mere mathematical diagram. Natural lines are never as straight as that.

*Fig.* 3. *Ordinary Folding.* This is not a wholly imaginary country. It is generalised from the structure of North Wales. The reader will observe that a great thickness of beds has been removed by waste from the core of the anticline.

*Figs.* 4 *and* 5. *Over-driven Fold and Thrust-plane.* The arrows indicate the directions from which the force was applied.

*Fig.* 6. *Unconformity.* The lowest bed of the upper series is supposed to be a conglomerate, with pebbles (suggested by flat rings) derived from the waste of the older series.

*Fig.* 7. *Slaty Cleavage.* The arrows indicate the directions from which the compressing force came. The cleavage, nearly vertical, fails to pass through the sandstones, which are shaded with dots.

*Fig.* 8. *Section across the Grand Canyon of the Colorado.* The wide upper part was cut when the country was lower and not so dry. Then the country was raised, the climate became dry, and the river cut the deep narrow canyon.

*Fig.* 9. *Escarpment and Dip-slope.* The hard beds are shaded with dots, the soft beds with lines.

*Fig.* 10. *Section across a Mountain-Chain.* The strong line represents the erosion-forms of the mountains. The broken lines in the air shew the parts of the folds which have been removed by waste. Complicated as this section looks, the structure of the Alps is far more complicated. Some of the high peaks are composed of beds which have been turned upside down.

*Fig.* 11. *Section across a Newly Explored Country.* The lowest bed of the Triassic System is supposed to be a conglomerate, with pebbles (suggested by flat rings) derived from waste of the Ordovician and Silurian rocks. The Ordovician lava could not have been folded until after the deposition of the Silurian rocks, by which time it must have cooled and have become quite hard.

## APPENDIX II

# Suggestions for Further Study

SOME readers of this little book, possessed by the fascination of the subject, may feel drawn to pursue it a good deal further. In which case, a few suggestions as to methods of doing so may be welcome.

*Books.* The first thing needed will be an elementary text-book. "Geology for Beginners," by Prof. W. W. Watts of the Imperial College of Science, will be found, in spite of the modesty of its title, to contain a large amount of information, and is very fully illustrated. This may be followed up by "A Text-book of Geology" by Lake and Rastall. A little elementary Chemistry, and some knowledge of the Zoological classification of animals, will be of great advantage, and the reader may be recommended to enquire for suitable books on those subjects. A general account of our own country is given in "The Geology of England and Wales," by Horace B. Woodward, though parts of this book stand in need of being brought up to date. It is hoped that a "Geology of Scotland" will be issued ere long by Dr. Horne. The development of the land-features of Britain is lucidly described in Lord Avebury's "Scenery of England," while Geikie's "Scenery of Scotland" is an admitted classic, and reads like a romance.

*Museums* (see pp. 9, 22). The enormous collection in the British Museum (Natural History) at South Kensington is somewhat overwhelming at first sight. But there are excellent guide-books to it, and lectures are given on certain days. A less known but more accessible collection is that of the Geological Survey, which is at present in Jermyn Street, close to Piccadilly Circus; while the Scottish Branch of the Survey has a similar collection in Edinburgh. The National Museum of Wales at Cardiff, though a young institution, has a fine geological collection, and is admirably organised. There are also many collections in provincial towns.

*Field-work.* But no books or museums can take the place of what we see along the country-side and under the open sky. Unless, however, a country be exceedingly simple, the beginner will soon find himself in difficulties without a geological map. Geikie's map of Scotland, on the scale of 10 miles to the inch, ought to be added to those mentioned on p. 48. Many of the sheets and "quarter-sheets" of the Geological Survey, on the scale of one inch to one mile, being colour-printed, are sold at very moderate prices; but the older sheets, which are hand-coloured, are somewhat expensive. A general account of the methods employed in field-work will be found in "Outlines of Field Geology," by Sir A. Geikie. The Geological Survey has published a large series of "Memoirs," which are books descriptive of the several districts covered by the maps, but to make good use of these Memoirs needs some knowledge of the science. A well-made geological map on the one-inch scale gives, not only the boundaries of the rock-formations in lines and colours, but the dip (shewn by arrows, with angles in degrees), as well as other information, so that the underground structure can often be inferred from it, and a section drawn. In any but a difficult country, the beginner armed with a one-inch map will find that he can soon make out the leading features of the geology. Should he find fossils, he may be earnestly requested to attach, before nightfall, a label to each fossil, giving the precise locality at which it was found. The fossil may be of more scientific value than he is aware, and its value will depend very largely upon a knowledge of the precise locality.

## NOTE

**These Appendices, being after-thoughts, never had the advantage of being read critically by her to whom this little book is dedicated.**